Dark Energy Survey and Camera

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Abstract. We describe the Dark Energy Survey and Camera. The survey will image 5000 sq. deg. in the southern sky to collect 300 million galaxies, 30,000 galaxy clusters and 2000 Type Ia supernovae. We expect to derive a value for the dark energy equation of state parameter, w, to a precision of 5% by combining four distinct measurement techniques. We describe the mosaic camera that will consist of CCDs with enhanced sensitivity in the near infrared. The camera will be mounted at the prime focus of the 4m Blanco telescope.

1. Introduction

The Dark Energy Survey (DES) is a proposal to collect 5000 sq. deg. of optical imaging data primarily in the region around the south galactic cap to make measurements that are sensitive to dark energy. The proposal comes as a response to a National Optical Astronomy Observatory announcement of opportunity (AO) for an instrument partnership with the 4m Blanco telescope at Cerro Tololo Inter-American Observatory (CTIO). To respond to this AO, we propose to build the DES instrument, which consists of a focal plane camera (DECam) with sixty-two 2K x 4K CCDs, an optical corrector, four filters (g, r, i, z), and the support and infrastructure for a new prime focus cage for the Blanco telescope. If we are selected and funded for this project, we will be awarded approximately 30% of the observing at CTIO over a five year period to conduct the survey. We expect to derive a value for the dark energy equation of state parameter, w, to a precision of 5% combining four distinct measurements.

2. Science

Dark energy has been labeled as one of the most important areas of scientific study for the next decade. Dark energy was first identified through the surprising observation that the expansion of the universe is accelerating. This observation followed from measurements of Type Ia supernovae (Riess et al. 1998; Perlmutter et al. 1999). Other indirect evidence for dark energy has been presented through a combination of the cosmic microwave background temperature anisotropy pattern, which points to a spatially flat universe, and of the distribution of large-scale structure and galaxy clusters that constrain the density of

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matter (luminous and dark) to about 30%. These studies suggest the remaining 70% of the energy density of the universe may be accounted by dark energy. While evidence continues to mount for a picture of the universe that is now dominated by dark energy, many more measurements are required to possibly confirm this picture and to constrain the possible sources and unknown nature of dark energy.

The DES will measure the effects of dark energy through four different measurement techniques: (1) a galaxy cluster survey to redshift of z∼1.1 containing 30,000 clusters, (2) a weak lensing study of cosmic shear extending to large angular scales, and (3) a galaxy angular power spectrum study to z ∼1.1 using 300 million galaxies, and (4) a time domain study of 40 sq. deg. in which 2000 Type Ia supernovae will be measured to a redshift of z∼0.8.

To study the effects of dark energy on the evolution of galaxy clusters, the imaging area is chosen to overlap the planned Sunyaev-Zel'dovich effect (SZE) survey by the South Pole Telescope (Carlstrom et al. 2000). The DES will provide photometric redshift information for approximately 90% of the clusters found through the SZE. Independent cluster identification and cluster mass determination through both the DES and SPT surveys will provide a means to understand systematic uncertainties. Figure 1 shows the forcast of the constraints on w compared with other representative forecasts.
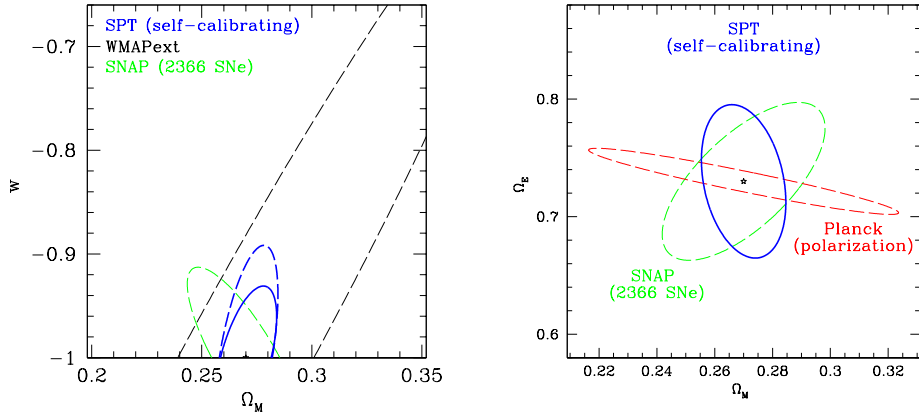

Figure 1.   Forecasts of the constraints on the dark energy equation of state parameter, w, the dark energy density parameter, Ω_E, and the matter density parameter, Ω_m for the DES+SPT galaxy cluster survey (blue). For comparison, forecasts for SNAP supernovae (green; Perlmutter & Schmidt 2003), current constraints from WMAPext (black; Spergel et al. 2003), and for Planck polarization (red; Eisenstein, Hu & Tegmark 1999) are shown. The cluster constraints in the left panel either assume a flat universe (solid blue) or solve for geometry and w simultaneously (dashed blue). The constraints arise from the cluster power spectrum, the cluster redshift distribution, and 100 cluster mass measurements (assumed distributed uniformly out to z = 1.2), each accurate at the 30% level (1σ). This forecast accounts for systematic uncertainties associated with cluster masses through the technique of self-calibration (Majumdar & Mohr 2003a,b).

The other three measurement techniques will also yield sensitivity to dark energy that is complimentary to the galaxy cluster survey. The weak lensing study will use both cosmic shear and shear-shear correlations. The technique to use the galaxy angluar power spectrum, where the power spectrum in redshift shells of width $\delta z \sim 0.1$ is analyzed, expects to determine w to 13% without an assumption of a flat universe. Finally, the sample of approximately 2000 Type Ia supernovae out to cosmically interesting redshifts should provide the largest such sample for study by the time the survey is completed. It is hoped that by combining all four measurement techniques and including the ability to correlate the SZE data from the SPT, the DES will provide new information on the nature of dark energy. DES will act as a precursor to even more ambitious future ground and spaced-based telescopes targeting the study of dark energy.

3.   Dark Energy Survey Instrument

The DES instrument includes a large focal plane camera, an optical corrector that provides flat field illumination, four filters, and all the infrastructure for operation at the 4m Blanco telescope. The camera and corrector will be assembled into a barrel-shaped cage that attaches to the Blanco telescope at the prime focus through supporting struts. The DECam consists of sixty-two 2K x 4K CCD modules arranged in a hexagon that can be inscribed in a diameter of 450 mm corresponding to an optical field-of-view of 2.2 deg. The area of the hexagon, which is relevant for the tiling area, is 3 sq. deg. Separate devices will be located at the edge of the focal plane for guiding and focusing. Figure 2 shows a cross section of the proposed instrument with the key elements identified.
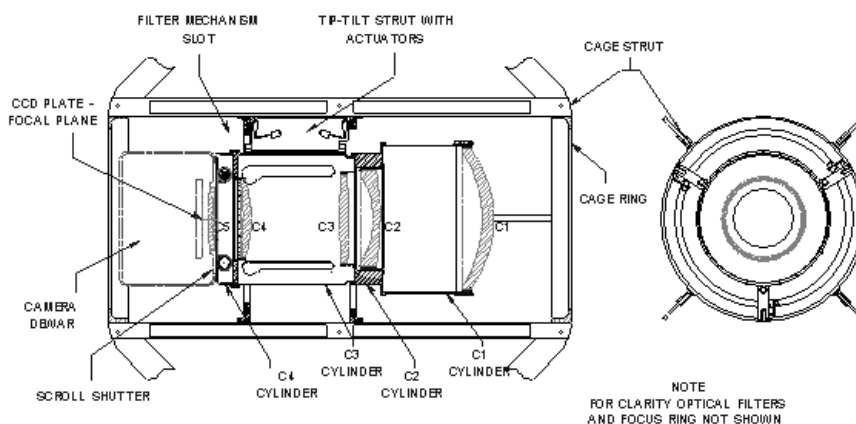

Figure 2.   Cross section of the Dark Energy Survey instrument showing the cage structure, camera, elements of the optical corrector, and filters.

A requirement for the CCD devices is that they have a high quantum efficiency (QE) of better than 40% for wavelenghts from 400 nm to 1000 nm. This QE has been achieved through 250 μm thick fully depleted CCDs built on high resistivity silicon developed at Lawrence Berkeley National Laboratory (LBNL) (Holland et al. 2003). At Fermilab, we will establish a packaging factory to produce four-side buttable modules. These modules will be tested and graded

using test stands which allow for illuminated and dark calibration images, an Fe^{55} calibration source, and the ability to characterize QE versus wavelength.

The camera vessel will house a precision plate that holds the CCD modules while connected thermally to a liquid nitrogen-filled dewar, which provides a CCD operating temperature between -120°C and -90°C. Flexible cables will carry signals from the CCDs to printed circuit boards that form part of the vacuum seal. Analog signals from the CCDs are converted into digital and recorded through the Monsoon data acquisition system, under development by NOAO, which also acts to provide clock sequencing and other control for operation.

The optical corrector consists of five optical elements - fused silica lenses - that produce flat illumination over the entire focal plane with the point spread function better than 0.4"(FWHM). The largest element is 1.1 m in diameter. Only one lens is ashperical. The window for the camera vessel has a small curvature and is located close (40mm) to the CCDs in order to minimize ghosting. The arrangement of the lenses includes space to allow for room so each of the four filters to be separately rotated into the optical path.

4.   Survey strategy and data management

The survey strategy is designed to obtain precise photometry required for photometric redshift determination. The 5000 sq. deg. area will be covered by overlapping and offset tiles in each of the four filters. Early in the survey, we will obtain a data sample that has S/N>10 for magnitudes of 24.2, 23.7, 23.3, and 22.6 for the g, r, i, z filters using coadded images from two tiles in each color. After five years, the relative (absolute) photometric calibration will have a precision better than 1%(2.2%) with a magnitude reach in the z-band of 23.9.

The data volume for the survey is expected to exceed 500 Tb and will consist of raw and processed images, databases, and catalogs generated through several pipelines. The imaging data, coadded images and catalogs will be made publically available through periodic data releases.

References

Carlstrom, J. et al. 2000, in Constructing the Universe with Clusters of Galaxies, eds. F. Durret & G. Gerbal (IAP: Paris)

Eisenstein, D. Hu, W., & Tegmark, M. 1999, ApJ, 518, 2

Holland, S. et al. 2003, IEEE Trans. Elec. Dev., 50, 225

Majumdar, S. & Mohr, J 2003a, ApJ, 585, 603

Majumdar, S. & Mohr, J 2003b, ApJ submitted (astro-ph/0305341)

Riess, A. et al. 1998, AJ, 116, 1009

Perlmutter, S. et al. 1999, ApJ, 483, 565

Perlmutter, S. & Schmidt, B. 2003, in Supernovae and Gamma-Ray Bursters, ed. K. Weiler (Springer: Berlin), vol. 598, p. 195.

Spergel et al. 2003, ApJS, 148, 175